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INTERNATIONAL STANDARD

Electric cables – Calculation of the current rating –
Part 2-1: Thermal resistance – Calculation of thermal resistance

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Part 2-1: Thermal resistance – Calculation of thermal resistance

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 2-1: Thermal resistance – Calculation of thermal resistance

FOREWORD

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IEC 60287-2-1 has been prepared by IEC technical committee 20: Electric cables. It is an International Standard.

This third edition cancels and replaces the second edition published in 2015. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) thorough redefinition of symbols used across the IEC 60287 and IEC 60853 series to realign and unify definitions, eliminate inconsistencies and to improve cross-use of the different parts of both IEC 60287 and IEC 60853 series;
b) improvement in the identification of tabulated materials and introduction of new materials in the tables;

c) introduction of generic annular layers to improve thermal modelling of existing and future cables designs;

d) improved calculation of T_4 in the case of directly buried cables;

e) introduction of corrective factors, on relevant calculated physical characteristics to take into account the effect of multicore lay-lengths; a dedicated annex to highlight correction factors for different number of cores has been introduced (Annex A);

f) improved description and formulation for the case of cables in pipe and backfill;

g) redefinition of the calculation method of T_4 for duct banks where $y/x > 3$, the new table based method eliminates errors, extends the usability of the new formulation while keeping a suitable conservative margin in the calculation.

The text of this International Standard is based on the following documents:

Draft	Report on voting
20/2099/FDIS	20/2106/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60287 series, published under the general title *Electric cables – Calculation of the current rating*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The IEC 60287 series has been divided into three parts so that revisions of, and additions to the document can be carried out more conveniently.

Each part is subdivided into subparts which are published as separate standards.

Part 1: Formulae of ratings and power losses;

Part 2: Formulae for thermal resistance;

Part 3: Operating conditions.

This part of IEC 60287-2 contains methods for calculating the internal thermal resistance of cables and the external thermal resistance for cables laid in free air, ducts and buried.

The formulae in this document contain quantities which vary with cable design and materials used. The values given in the tables are either internationally agreed, for example, electrical resistivities and resistance temperature coefficients, or are those which are generally accepted in practice, for example, thermal resistivities and permittivities of materials. In this latter category, some of the values given are not characteristic of the quality of new cables but are considered to apply to cables after a long period of use. In order that uniform and comparable results can be obtained, the current ratings should be calculated with the values given in this document. However, where it is known with certainty that other values are more appropriate to the materials and design, then these may be used, and the corresponding current rating declared in addition, provided that the different values are quoted.

Quantities related to the operating conditions of cables are liable to vary considerably from one country to another. For instance, with respect to the ambient temperature and soil thermal resistivity, the values are governed in various countries by different considerations. Superficial comparisons between the values used in the various countries can lead to erroneous conclusions if they are not based on common criteria: for example, there can be different expectations for the life of the cables, and in some countries design is based on maximum values of soil thermal resistivity, whereas in others average values are used. Particularly, in the case of soil thermal resistivity, it is well known that this quantity is very sensitive to soil moisture content and can vary significantly with time, depending on the soil type, the topographical and meteorological conditions, and the cable loading.

The following procedure for choosing the values for the various parameters should, therefore, be adopted:

Numerical values should preferably be based on results of suitable measurements. Often such results are already included in national specifications as recommended values, so that the calculation may be based on these values generally used in the country in question; a survey of such values is given in IEC 60287-3-1.

A suggested list of the information required to select the appropriate type of cable is given in IEC 60287-3-1.

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 2-1: Thermal resistance – Calculation of thermal resistance

1 Scope

This part of IEC 60287 is solely applicable to the conditions of steady-state operation of cables at all alternating voltages, and direct voltages up to 5 kV, buried directly in the ground, in ducts, in troughs or in steel pipes, both with and without partial drying-out of the soil, as well as cables in air. The term "steady state" is intended to mean a continuous constant current (100 % load factor) just sufficient to produce asymptotically the maximum conductor temperature, the surrounding ambient conditions being assumed constant.

This document provides formulae for thermal resistance.

The formulae given are essentially literal and designedly leave open the selection of certain important parameters. These can be divided into three groups:

– parameters related to construction of a cable (for example, thermal resistivity of insulating material) for which representative values have been selected based on published work;

– parameters related to the surrounding conditions which can vary widely, the selection of which depends on the country in which the cables are used or will be used;

– parameters which result from an agreement between manufacturer and user and which involve a margin for security of service (for example, maximum conductor temperature).

Equations given in this document for calculating the external thermal resistance of a cable buried directly in the ground or in a buried duct are for a limited number of installation conditions. Where analytical methods are not available for calculation of external thermal resistance finite element methods can be used. Guidance on the use of finite element methods for calculating cable current ratings is given in IEC TR 62095.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60287-1-1:2023, *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*

IEC 60853-2, *Calculation of the cyclic and emergency current rating of cables – Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages*

3 Terms, definitions and symbols

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.2 Symbols

The symbols used in this document and the quantities which they represent are given in the following list:

C_{fL}	factor to take into account the position of the neutral axis of the helically wound cores	
C_{K1}	screening factor for the thermal resistance of screened cables	
C_{LL}	length correction factor for considering laying up of cores	
D'_{a}	external diameter of armour	mm
D_{d}	internal diameter of duct	mm
D_{e}	external diameter of cable, or equivalent diameter of a group of cores in pipe-type cable	mm
D^{*}_{e}	external diameter of cable (used in 4.2.1)	m
D_{o}	external diameter of duct	mm
D_{s}	external diameter of metal sheath	mm
D_{oc}	diameter of the imaginary coaxial cylinder which just touches the crests of a corrugated sheath	mm
D_{ot}	diameter of the imaginary coaxial cylinder which would just touch the outside surface of the troughs of a corrugated sheath = $D_{\mathrm{it}} + 2t_{\mathrm{s}}$	mm
D_{ic}	diameter of the imaginary cylinder which would just touch the inside surface of the crests of a corrugated sheath = $D_{\mathrm{oc}} - 2t_{\mathrm{s}}$	mm
D_{it}	diameter of the imaginary cylinder which just touches the inside surface of the troughs of a corrugated sheath	mm
D_{I}	the inner diameter of any generic annular concentric cable element layer	mm
E	constant used for the heat dissipation in air coefficient in 4.2.1.1	
E_{e}	intensity of solar radiation	W/m^2
F_1	coefficient for belted cables defined in 4.1.2.2.3	
F_2	coefficient for belted cables defined in 4.1.2.2.6	
G	geometric factor for belted cables	
$\overline{G}$	geometric factor for SL and SA type cables	
K_{A}	coefficient used in 4.2.1	
L	depth of laying, to cable axis or centre of trefoil	mm
L_{G}	distance from the soil surface to the centre of a duct bank	mm

L_L^*	axial cable length over which the cores make one full helical turn (m)	
N_L	number of loaded cables in a duct bank (see 4.2.7)	
P_h	part of the perimeter of the cable trough which is effective for heat dissipation (see 4.2.5.2)	m
T_1	thermal resistance per core between conductor and sheath	K · m/W
T_2	thermal resistance between sheath and armour	K · m/W
T_3	thermal resistance of external serving	K · m/W
T_4	thermal resistance of surrounding medium (ratio of cable surface temperature rise above ambient to the losses per unit length)	K · m/W
T_4^*	external thermal resistance in free air, adjusted for solar radiation	K · m/W
T_4'	thermal resistance between cable and duct (or pipe)	K · m/W
T_4''	thermal resistance of the duct (or pipe)	K · m/W
T_4'''	thermal resistance of the medium surrounding the duct (or pipe)	K · m/W
U	constant used in 4.2.6.3	
V	constant used in 4.2.6.3	
W_d	dielectric losses per unit length per phase	W/m
W_k	losses dissipated by cable k	W/m
W_{TOT}	total power dissipated in the trough per unit length	W/m
Y	coefficient used in 4.2.6.3	
Z	coefficient used in 4.2.1.1	
C_g	coefficient used in 4.2.1.1	
d_a	external diameter of belt insulation	mm
d_c	external diameter of conductor	mm
d_{cm}	minor diameter of an oval conductor	mm
d_{cM}	major diameter of an oval conductor	mm
d_M	major diameter of screen or sheath of an oval conductor	mm
d_m	minor diameter of screen or sheath of an oval conductor	mm
d_x	diameter of an equivalent circular conductor having the same cross-sectional area and degree of compactness as the shaped one	mm
h	heat dissipation coefficient	$W/m^2K^{5/4}$
h_b	height of the duct bank or backfill	mm
ln	natural logarithm (logarithm to base e)	
n	number of conductors in a cable	
r_1	circumscribing radius of two- or three-sector shaped conductors	mm
s_1	axial separation of two adjacent cables in a horizontal group of three, not touching	mm
t	insulation thickness between conductors	mm
t_1	insulation thickness between conductors and sheath	mm
t_2	thickness of the bedding	mm

t_3	thickness of the serving		mm
t_i	thickness of core insulation, including screening tapes plus half the thickness of any non-metallic tapes over the laid-up cores		mm
t_l	thickness of any generic annular concentric cable element layer		mm
t_s	thickness of the sheath		mm
u_1	symbol used throughout the document e.g. in 4.2		
U_2	symbol used throughout the document e.g. in 4.2.6.5		
w_b	width of the duct bank or backfill		mm
θ_m	mean temperature of medium between a cable and duct or pipe		°C
$\Delta\theta$	permissible temperature rise of conductor above ambient temperature		K
$\Delta\theta_{d0}$	factor to account for dielectric loss for calculating T_4 for cables in free air		K
$\Delta\theta_{ds}$	factor to account for both dielectric loss and direct solar radiation for calculating T_4^* for cables in free air using Figure 10		K
$\Delta\theta_{duct}$	difference between the mean temperature of air in a duct and ambient temperature		K
$\Delta\theta_s$	difference between the surface temperature of a cable in air and ambient temperature		K
$\Delta\theta_{tr}$	temperature rise of the air in a cable trough		K
λ_1	ratio of the total losses in metallic sheaths to the total conductor losses (or losses in one sheath to the losses in one conductor)		
λ'_{1m}	loss factor for the middle cable	Three cables in flat formation without transposition, with sheaths bonded at both ends	
λ'_{11}	loss factor for the outer cable with the greater losses		
λ'_{12}	loss factor for the outer cable with the least losses		
λ_2	ratio of the total losses in armour to the total conductor losses (or losses in one armour to the losses in one conductor)		
ρ	thermal resistivity of the soil		K · m/W
ρ_i	thermal resistivity of the insulation		K · m/W
ρ_f	thermal resistivity of the filler material		K · m/W
ρ_e	thermal resistivity of earth surrounding a duct bank		K · m/W
ρ_c	thermal resistivity of concrete used for a duct bank		K · m/W
ρ_m	thermal resistivity of metallic screens on multicore cables		K · m/W
ρ_T	thermal resistivity of material		K · m/W
Σ	absorption coefficient of solar radiation for the cable surface		

4 Calculation of thermal resistances

4.1 Thermal resistance of the constituent parts of a cable, T_1, T_2 and T_3

4.1.1 General

Clause 4 gives the formulae for calculating the thermal resistances per unit length of the different parts of the cable T_1, T_2 and T_3 (see IEC 60287-1-1:2023, Clause 4). The thermal resistivities of materials used for insulation and for protective coverings are given in Table 1.

Subject to agreement between the manufacturer and user, measured values of the thermal resistivities may be used both for tabulated or new materials.

Where screening layers are present, for thermal calculations, metallic tapes are considered to be part of the conductor or sheath while semi-conducting layers (including metallized carbon paper tapes) are considered as part of the insulation. The appropriate component dimensions shall be modified accordingly.

4.1.2 Thermal resistance between one conductor and sheath T_1

4.1.2.1 Single-core cables

The thermal resistance between one conductor and the sheath T_1 is given by:

$$T_1 = \frac{\rho_1}{2\pi} \ln\left(1 + \frac{2\,t_1}{d_c}\right) \cdot \frac{1}{C_{LL}}$$

where

ρ_1 is the thermal resistivity of insulation (K · m/W);

d_c is the diameter of the conductor (mm);

t_1 is the thickness of insulation between the conductor and sheath (mm);

C_{LL} is the length correction factor for considering laying up cores. A proposal for its calculation is given in Annex A.

In case more detailed evaluation of T_1 is preferred, for concentric annular layers as in the case where the conductor screen and the insulation screen are to be considered separately, the formulation of 4.1.3 should be used for each separate layer.

NOTE For corrugated sheaths, t_1 is based on the mean internal diameter of the sheath which is given by:

$$\left(\frac{D_{it} + D_{oc}}{2}\right) - t_s$$

4.1.2.2 Belted cables

4.1.2.2.1 General

The thermal resistance T_1 between one conductor and sheath is given by:

$$T_1 = \frac{\rho_T}{2\pi} G$$

where

G is the geometric factor.

NOTE For corrugated sheaths, t_1 is based on the mean internal diameter of the sheath which is given by:

$$\left(\frac{D_{it} + D_{oc}}{2}\right) - t_s$$

4.1.2.2.2 Two-core belted cables with circular conductors

The geometric factor G is given in Figure 2.

4.1.2.2.3 Two-core belted cables with sector-shaped conductors

The geometric factor G is given by:

$$G = 2\,F_1 \ln\left(\frac{d_a}{2\,r_1}\right)$$

where

$$F_1 = 1 + \frac{2{,}2\,t}{2\pi\,(d_x + t) - t};$$

d_a is the external diameter of the belt insulation (mm);

r_1 is the radius of the circle circumscribing the conductors (mm);

d_x is the diameter of a circular conductor having the same cross-sectional area and degree of compaction as the shaped one (mm);

t is the insulation thickness between conductors (mm).

4.1.2.2.4 Three-core belted cables with circular conductors

For three-core belted cables with circular conductors

$$T_1 = \frac{\rho_i}{2\pi} G + 0{,}031\,(\rho_f - \rho_i)\,e^{0{,}67\frac{t_1}{d_c}} \tag{1}$$

where

ρ_i is the thermal resistivity of the insulation (K · m/W);

ρ_f is the thermal resistivity of the filler material (K · m/W).

The geometric factor G is given in Figure 3.

For paper-insulated cables $\rho_f = \rho_i$ and, hence, the second term on the right hand side of Equation (1) can be ignored.

For cables with extruded insulation, the thermal resistivity of the filler material is likely to be between 6 K · m/W and 13 K · m/W, depending on the filler material and its compaction. A value of 10 K · m/W is suggested for fibrous polypropylene fillers.

The above Equation (1) is applicable to cables with extruded insulation where each core has an individual screen of spaced wires and to cables with a common metallic screen over all three cores. For unarmoured cables of this design t_1 is taken to be the thickness of the material between the conductors and outer covering (serving).

4.1.2.2.5 Three-core belted cables with oval conductors

The cable shall be treated as an equivalent circular conductor cable with an equivalent diameter $d_c = \sqrt{d_{cM} \times d_{cm}}$ (mm)

where

d_{cM} is the major diameter of the oval conductor (mm);

d_{cm} is the minor diameter of the oval conductor (mm).

4.1.2.2.6 Three-core belted cables with sector-shaped conductors

The geometric factor G for these cables depends on the shape of the sectors, which varies from one manufacturer to another. A suitable formula is:

$$G = 3 F_2 \ln\left(\frac{d_a}{2 r_1}\right)$$

where

$$F_2 = 1 + \frac{3t}{2\pi (d_x + t) - t};$$

d_a is the external diameter of the belt insulation (mm);

r_1 is the radius of the circle circumscribing the conductors (mm);

d_x is the diameter of a circular conductor having the same cross-sectional area and degree of compaction as the shaped one (mm);

t is the insulation thickness between conductors (mm).

4.1.2.3 Three-core cables, metal tape screened type

4.1.2.3.1 Screened cables with circular conductors

Paper insulated of this type may be first considered as belted cables for which $\frac{t_1}{t}$ is 0,5. Then, in order to take account of the thermal conductivity of the metallic screens, the result shall be multiplied by a factor C_{K1}, called the screening factor, which is given in Figure 4 for different values of $\frac{t_1}{d_c}$ and different cable specifications.

Thus:

$$T_1 = C_{K1} \frac{\rho_T}{2\pi} G$$

Three-core cables with extruded insulation and individual copper tape screens on each core should be treated as SL type cables (see 4.1.2.5 and 4.1.4.2).

See 4.1.2.2.4 for three-core cables with extruded insulation and an individual screen of spaced copper wires on each core or a common metallic screen over all three cores.